SIMULATION OF HYBRID SERIES ACTIVE FILTER FOR HOUSEHOLD APPLICATION

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ABSTRACT

To improve the power quality of a single-phase residential household, a Multilevel Transformer less Hybrid Series Active Filter (Multilevel-THSeAF) is proposed in this study. The proposed topology reflects new consumer tendencies toward electronic polluting loads and renewable energy integration, which could lead to the possibility of a reliable and sustainable supply. This work adds to the enhancement of power quality in a modern single-phase system by emphasising the integration of a compensator with energy storage capacity in order to secure a long-term supply. The controller includes a proportional resonant (PR) regulator to prevent current harmonic distortions from diverse non-linear loads from flowing into the utility. The suggested topology's key advantages are its capacity to concurrently fix the power factor and clean the grid while protecting consumers from voltage disturbances, sags, and swells during a grid perturbation. It looks into harmonic compensation and evaluates the impact of the controller's choice and time delay in a real-time implementation. Validation is presented using a combination of analytical and experimental results from a laboratory setup.

Keywords: SAPF, THSeAF, PR, THD.

Introduction

The enormous increase in the usage of non-linear loads in recent years has raised many power quality issues on the electrical grid, including excessive current harmonics, voltage distortion, and low power factor, among others [1]. As a result of the increasing nonlinear demand in the system, harmonic currents are injected into the AC power lines. This distorted supply voltage and current causes certain protection devices to fail, transformers and motors to burn, and wires to overheat. As a result, it is essential to install compensating devices to compensate for harmonic currents and voltages generated by nonlinear loads. Passive power filters have traditionally been used as a compensatory device to reduce distortion caused by continuous non-linear loads. With a simple design and cheap cost, these filters are intended to offer a low impedance path for harmonics while maintaining acceptable power quality. However, passive filters have a number of drawbacks, including mistuning, resonance, reliance on power supply system settings, and high passive component values, which result in bulky implementations. Because of the rising need for non-linear loads, harmonic interference has become an important concern in power systems. Harmonic pollution is caused by harmonic interference. This harmonic pollution has a wide-ranging influence on the energy utility, including increased losses in the power system, a fall in power factor, and malfunctions in consumer equipment. Passive power filters (PPFs) have traditionally been used to reduce harmonic pollution. However, PPFs have significant issues like as enormous size, mistuning, resonance phenomena, and so on. The shunt active power filter is developed in the mid-1940s to address the inadequacies of PPFs. However, due of its high rating, active filters are extremely expensive. The active filter is unsuitable for large-scale businesses due to its high cost. In the future, a hybrid passive-active filter technology will be developed to mitigate the drawbacks of active filters. HSAPF is a HAPF topology that is effective at compensating both voltage and current harmonics, as well as reactive power. HSAPF also outperforms both kinds of nonlinear loads, such as voltage-type and current-type harmonic loads. A voltage-type harmonic load is a three-phase full bridge diode rectifier with a larger dc capacitor connected in parallel with the DC resistor. A current-type harmonic load is created by a 3-phase diode bridge rectifier with an inductor in series with the resistor on the output side.

Choosing the appropriate reference compensating voltage increases the HSAPF system's performance. In this work, the pq-theory was applied in the reference generating procedure. This theory is employed to generate compensatory voltage. The performance of the proposed HSAPF with p-q control approach has been determined to be viable for both current-type and voltage-type harmonic loads. The reference voltage is directly affected by the load voltages and source currents. Because it is

computationally simple and easy to develop, the hysteresis voltage controller is used to produce switching patterns. The control approach is crucial for increasing the performance of HSAPF. Many articles on hybrid power filters have already developed methods for decreasing current harmonics induced by nonlinear loads. In this study, a linear feedback-feedforward controller is designed for a hybrid power filter. However, since the dynamic model of the HSAPF system includes multiplication terms of control inputs and state variables, it is challenging for this controller to achieve both steady-state and transient state performances using the linear control approach. Because of the nonlinear features of HSAPF, this paper proposes a sliding mode controller. Because of its order reduction feature and low sensitivity to disturbances and plant parameter fluctuations, sliding mode control is recognised as an excellent control approach for dealing with nonlinear systems with unexpected dynamics and disturbances, decreasing the burden of precise modelling. Furthermore, by separating the system into discrete subsystems of lower size, this sliding mode control minimises the complexity of feedback control design. Because of these characteristics, sliding mode control is used in the domains of power electronic switching devices.

Survey of Earlier Work

According to Sushree Diptimayee Swain, Pravat Kumar Ray, and Kanungo Barada Mohanty [1], power quality degradation has a negative economic impact on utilities and customers. One of the most well-known power quality challenges is harmonics in current and voltage, which can be handled by using a hybrid series active power filter (HSAPF). To make the HSAPF more robust and reliable, a novel controller design based on sliding mode controller-2 is proposed in this study. In this research, an accurate averaged model of three-phase HSAPF is also developed. The resilient HSAPF design concept has been validated by simulation and experimental experiments, and the results have been discussed.

Narendra Babu p, Biswajit Kar, and Biswajit Halder [2] found that when technology advances, the demand for electricity grows at an exponential rate. For continuous operation, many instruments demand high-quality electricity. Consumer appliances necessitate high-quality power. However, the quality power distribution is pompous to the consumer's side due to some inner and outside components. In the power system network, there are differences in current, voltage, and frequency quality of power problems. Because of their high switching characteristics, power electronic converters are the primary source of power quality concerns.

Improvement of power quality (PQ) has become a vital feature in the current state of the power system, according to Soumya Ranjan Das, Prakash. K. Ray, and Asit Mohanty [3]. Passive filters, shunt filters, and series filters have been used in the past to increase power quality, however they have issues such as resonance, fixed compensation, and other PQ issues. As a result, a hybrid set of filters, including passive and active power filters (APF), is utilised to address these concerns. This work proposes a comparison and analysis of two alternative hybrid active power filter techniques (HAPF). The HAPF is set up using a series, passive, and shunt filter configuration.

According to Yang-Wen Wangl, Man-Chung Wongl, and Chi-Seng Laml [4], the hybrid active power filter (HAPF) has already proven to be a successful and widely-used technology for improving power quality.

The historical review and progress of the HAPFs' harmonic and reactive power compensation functionalities are presented in this study. The structures of HAPFs are discussed and divided into four developing patterns: parallel active part with parallel element, parallel active part with series element, b-shape, and three-phase four-wire structure. Its goal is to conduct a thorough examination of HAPFs' historical development trends in structure and function design.

Carlos H. da Silva, R. B. Gonzatti, S. C. Ferreira, R. R. Pereira, L. E. Borges da Silva, G. Lambert-Torres, Se Un Ahn [5] has describe that Hybrid active series power filters, as originally described, presents a means to improve the physical limitation of tuned passive filters. These enhancements, however, are limited to one filter parameter: quality or adjusted factor. The active impedance has been proposed to address these restrictions. By handling both the quality and the tuned factor at the same time, the topology can compensate for multiple harmonic currents with just a single tuned passive filter. The intricacies of the active impedance idea are demonstrated in this work. The active filter complex gain is implemented using an appropriate control technique based on PR Controller.

Power Quality Issues and Its Consequences

Any power fault exhibited in voltage, current, or frequency variation that causes client equipment to fail or malfunction is referred to as a power quality problem. Electronic equipment is both the culprit and the victim when it comes to power quality. While most contemporary electronic appliances are more energy efficient than their mechanical ancestors, they use electricity in a different way than old mechanical appliances.

The increased usage of solid state switching devices, nonlinear and power electronically switched loads, and electronic type loads has resulted in power supply quality challenges and problems. Because of the widespread use of high-power semiconductor switches, non-sinusoidal currents exist in the distribution and transmission lines.

Sources of Harmonics

Equipment using Power Electronic Devices

- AC & DC Drives
- Frequency Converters
- Rectifiers or Inverters
- Arc & Induction furnaces & ovens
- UPS
- Compact Fluorescent & other discharge Lamps

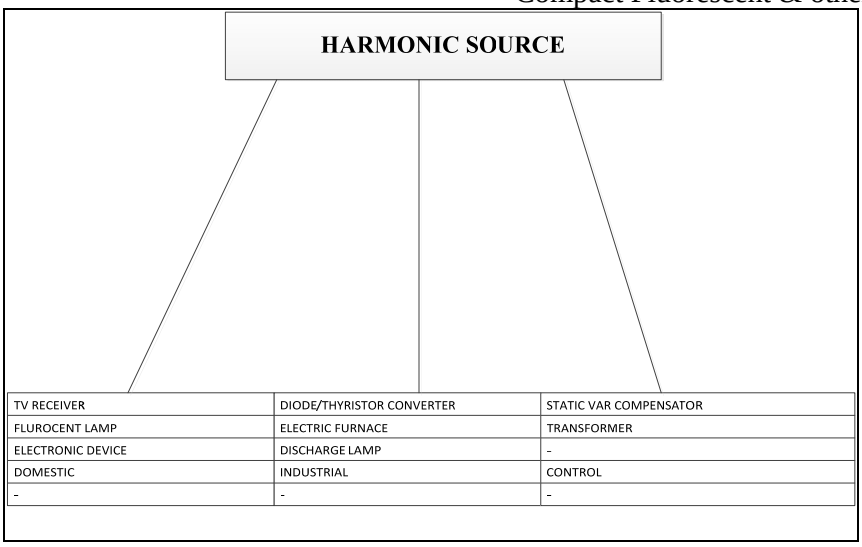

Figure-1: Harmonic source

Harmonic Sources from Industrial Loads

The extensive use of nonlinear loads is a feature of modern industrial facilities.

These loads can account for a large percentage of total facility loads and pump harmonic currents into the power system, generating voltage harmonic distortion. The fact that these nonlinear loads have a very low power factor adds to the harmonic problem. To avoid penalty charges, industrial facilities frequently use capacitor banks to boost the power factor.

Power factor correction capacitors have the potential to magnify harmonic currents from nonlinear loads, resulting in resonance conditions within the facility. The capacitors are frequently applied to the facility's low voltage bus, which has the highest voltage distortion. Overheating of motors and transformers, as well as the failure of sensitive electronic equipment, are caused by resonance situations.

Three types of nonlinear industrial loads can be identified: three-phase power converters, arcing devices, and saturable devices.

Equipment using Switched Mode Power Supply

- Television
- Computers, other IT Loads

Effects Of Harmonics

- Problem caused by harmonics
- over loading of neutral
- Overheating of neutral
- nuisance tripping of circuit barker
- skin effect
- Overheating of induction motor

Wave form distortion is often discussed in terms of harmonic which are sinusoidal voltage or current having high frequency that are the multiple of the frequency at which supply system is constructed to

run when the frequency of this voltage & current are termed as inter harmonics. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example if the fundamental frequency 50Hz, then 3rd is 150Hz, 5th is 250Hz. ideally, voltage and current waveforms are perfect sinusoids. However, due of the rising popularity of electronic and non-linear loads, these waveforms get distorted. This divergence from a perfect sine wave can be represented by harmonic components having a frequency that is an integral multiple of the fundamental frequency.

Hybrid Series Active Power Filter

The principle of sliding mode control is to use discontinuous control to impose sliding mode motion in a designated switching surface of the system state space. The switching surfaces should be chosen so that sliding motion maintains the desired motion dynamics according to a set of performance criteria. To choose optimal switching surfaces, traditional control methods such as Linear-quadratic regulator (LQR) or Linear quadratic Gaussian (LQG) servo controller for linear systems are necessary. The discontinuous control must then be chosen in such a way that all states outside of the discontinuity surface must reach it in a finite amount of time. As a result, the system enters a sliding mode down the surface and follows the intended system dynamics. Chattering is the most difficult aspect of implementing the classic sliding mode control mechanism in hardware. Chattering is a type of oscillation with a finite frequency and amplitude that is unwelcome. The chattering is problematic because the system lacks control accuracy, moving mechanical elements wear out quickly, and electrical power circuits lose a lot of heat. Because of unmodeled dynamics, chattering arises. Servomechanisms, sensors, and data processors with reduced time constants are used to create these unmodeled dynamics. The switching frequency in sliding mode control should be high enough to make the controller more robust, stable, and free of chattering, as chattering decreases as the switching frequency of the system increases. Increased switching frequency is a natural technique to prevent chattering when using a sliding mode controller in power converter systems, such as HSAPF. However, due to certain constraints in switching frequency for losses in power converters, it is not practicable in the case of power converters, resulting in chattering. As a result, the chattering problem cannot be blamed on the implementation of sliding mode because it is primarily caused by switching constraints. When the relative degree of the system with actuators or sensors is two, the chattering exponentially tends to zero, as illustrated in this study. Differences in current, voltage, and frequency power quality concerns will arise in the power system network [2], with currents deviating due to nonlinear loads. If there is a power quality problem in the power system network, the appliances in the network will be harmed or fail. In addition, equipment efficiency and performance have decreased [2]. Hybrid Active Power Filters (HAPF), notably shunt HAPF, are used to reduce harmonics and improve power quality. Active and passive filters are combined in hybrid Active Power filters [2]. The HAPF is a combination of a passive filter and an active power filter (APF). Passive filters are used to filter out selected harmonics, but they have several drawbacks, such as parallel resonance, larger size, and constant filtering feature, which makes it pretentious by the source impedance, therefore active power filters and HAPF were invented to alleviate these drawbacks [2].

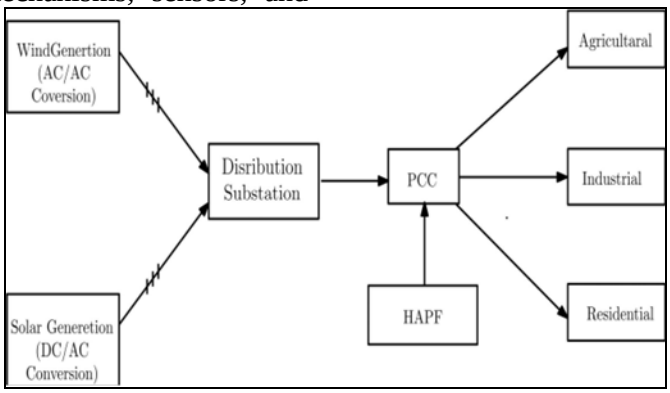

Fig. 2 Location of HAPF in Power system Network

This work discusses the modelling, analysis, and comparison of the HAPF, which is a Shunt Passive Filter in series with an active power filter, with compensation currents derived using instantaneous reactive power theory and Fryze current compensation theories to reduce harmonics. The values of Total Harmonic Distortion (THD) under various loading circumstances are listed, along with the MATLAB/SIMULINK findings. The overall system consists of a three-phase AC supply, a nonlinear load, an RL load, PF, APF, a three-phase universal bridge, an imbalanced resistive load, a Hysteresis Current Controller, and a PI Controller. Using the alpha beta transformation, the instantaneous reactive power theory estimates actual (p) and reactive power (q). Inverse Clark's transformation is used to calculate compensatory currents. The HCC receives these compensatory currents as input. The pulses for the filter inverter are generated by HCC. The position of HAPF is depicted in Figure 2. The overall structure of proposed system is shown in Fig 3.

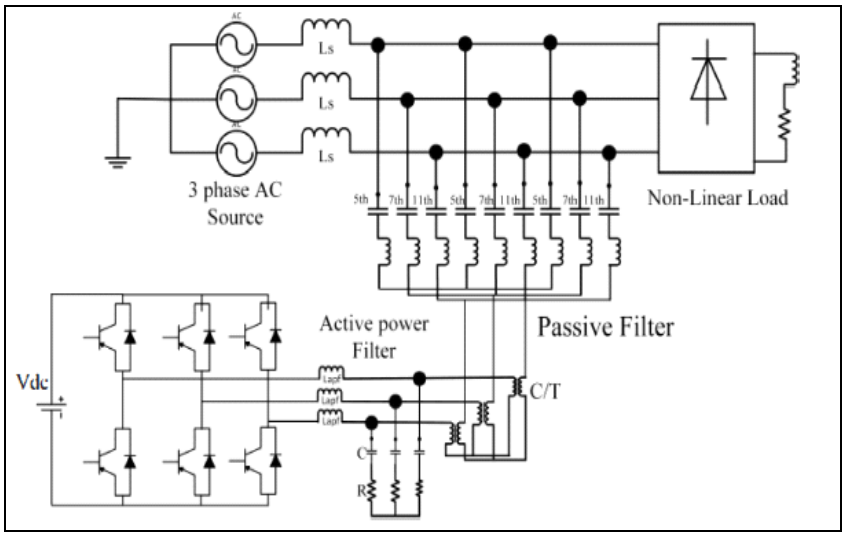

Fig 3- Block Diagram of Hybrid Active Power Filter

Controlling of Hybrid Series Active Power Filter

The relative degree of HSAPF system is two. Because of this relative degree of HSAPF system and also for these obstacles in classical sliding mode controller, this research paper proposed a new controller i.e. sliding mode controller-2. This proposed controller suppressed chattering and enhance the performance of HSAPF. This controller is completely new for this topology of HSAPF system.

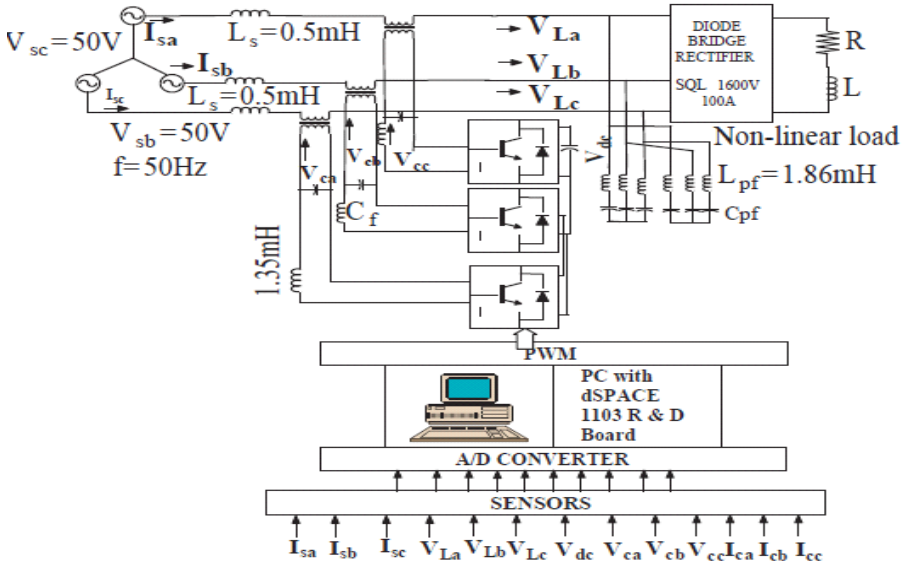

Fig. 4: Schematic diagram of the control and power circuit of HSAPF

For the HSAPF architecture, recent research has focused on carrier based PWM (CBPWM). However, in most real-world scenarios, the CBPWM-based HSAPF may not be totally measurable. In the case of CBPWM, power system perturbations are not taken into account, and the presence of a temporal delay at the reference tracking point causes the total system to respond slowly. As a result, tracking error is not significantly decreased, and system stability is only somewhat enhanced.

To address this, an SMC-2 controller for voltage source converters is proposed (VSC). The goal of this controller is to provide perfect tracking, gain stability, and distortion-free current and load voltage. In light of the aforementioned issues, we place a greater emphasis on the development of a robust controller with a faster reference tracking approach in HSAPF, which allows for all perturbations such as load voltage distortion, parametric load variation, source current distortion, and supply voltage unbalance, thereby improving the HSAPF system's compensation capability. The control and power circuit of the 3-phase HSAPF is shown schematically in Fig.4.A voltage source inverter and a three phase linear transformer make up the SAPF, which is coupled to the grid via an LC filter. The inductors' series resistance is not taken into account.Where Va, Vb, and Vc represent the duty cycle of the inverter legs in a switching period, and Vca, Vcb, Vcc represent the output voltage of a three-phase series active filter, and Ica, Icb, Icc represent the three-phase current output of the active filter, VaN, VbN, VcN represent the phase voltages for three phases, Isa, Isb, Isc represent the three-phase source current, and V.

Simulation And Result Discussion

Matlab Simulation of Three Phase SAPF system

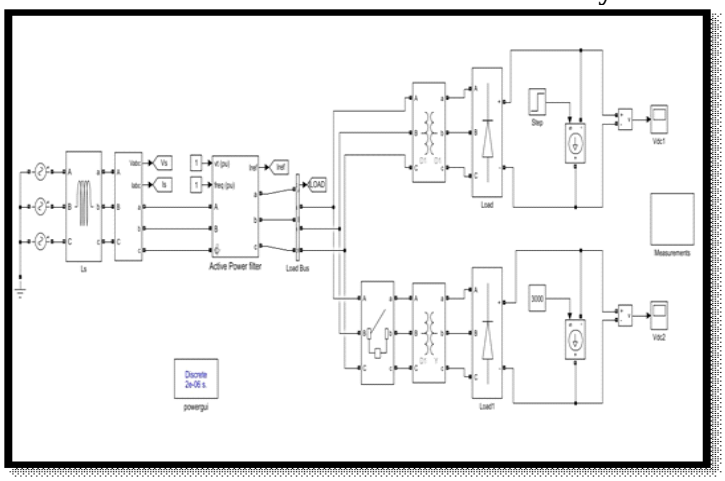

Fig 5 Matlab simulation of 3-phase APF system

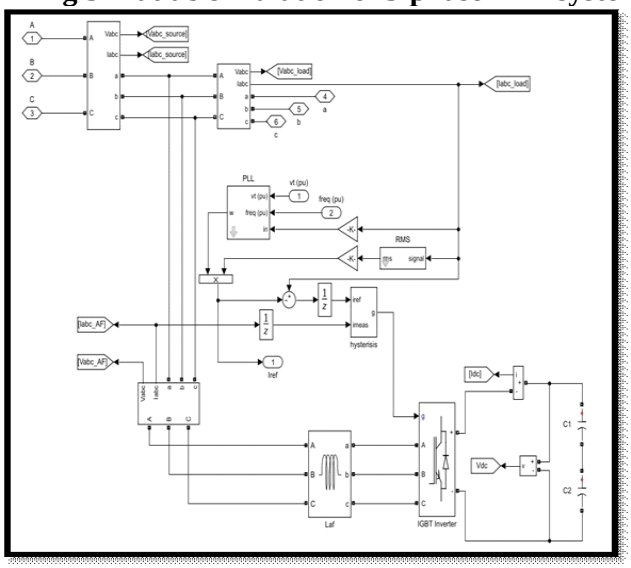

Fig 6 APF subsystem

Simulation Results

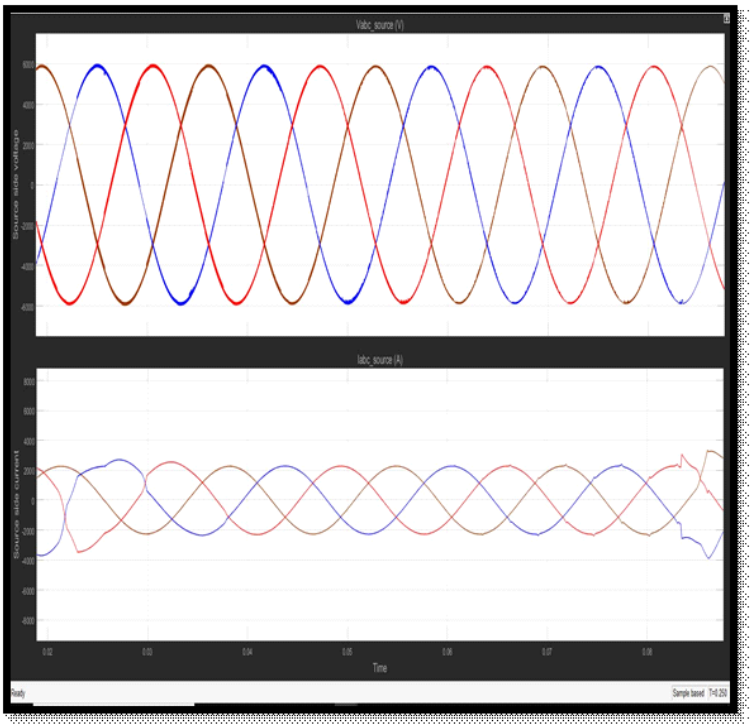

Fig 7 Source side voltage and current

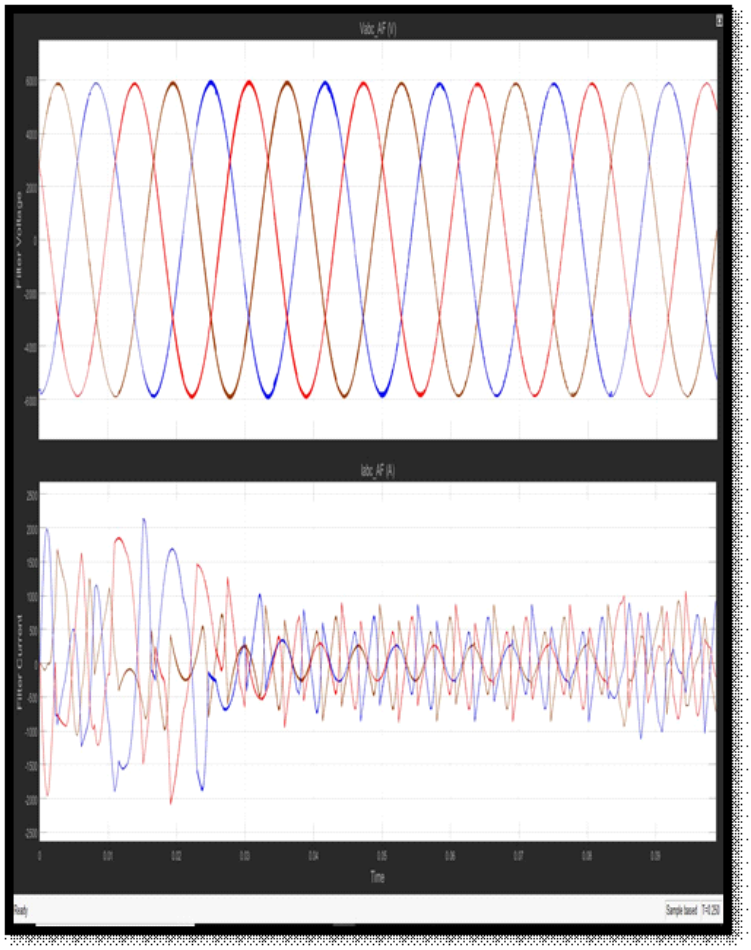

Fig 8 Filter side voltage and current

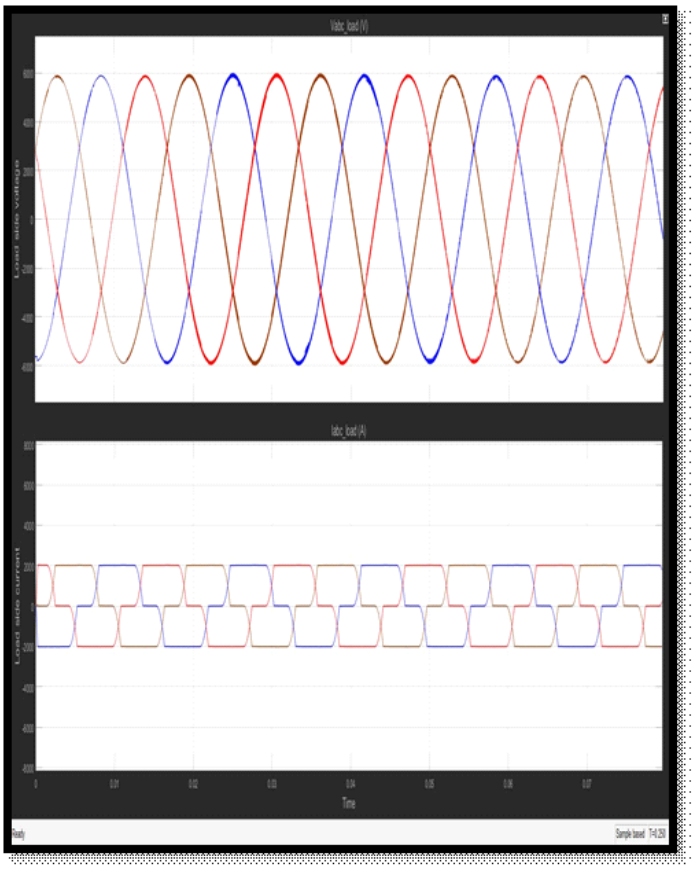

Fig 9 Load side voltage and current

Conclusion

A new robust controller design for HSAPF is proposed in this research. The corresponding control law is derived by sliding mode controller-2, which establishes the control design. This control law is quite useful for creating switching patterns. The suggested controller's robustness has been demonstrated by examining the power system's performance in both steady and transient states. After conducting a thorough investigation into our topic, we have come to the conclusion that the increased use of static power converters and static power capacitors can result in system conditions that produce power quality issues such as harmonics in the power system. The suggested filter compensates source currents and adjusts itself to accommodate for variations in non-linear load currents, keeps the dc link voltage consistent, and aids in power factor correction on the supply side near unity. We have designed a Matlab simulation of Series APF for Voltage Waveform Improvement in this work.

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